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FAR-INFRARED OBSERVATION OF THE GALACTIC-CENTER REGION AT 100 MICRONS

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ABSTRACT

An intense far-infrared source has been detected at 100 μ in the direction of the galactic center. The source has an extension along the galactic plane of at least 6°.5, a flux density of $1.8 \pm 0.8 \times 10^{-19}$ W m^{-2} Hz^{-1}, and a brightness temperature averaged over a 2°.3 beam width of 16° K. If the source is at the distance of the galactic center, its luminosity is 2.7×10^{42} ergs sec^{-1}. A possible mechanism is thermal emission of interstellar dust grains. The intensity is 30 times that anticipated for this process.

I. INTRODUCTION

During a balloon flight on July 30, 1968, we detected an intense far-infrared source in the direction of the galactic center. The source appears to be extended at least 6°.5 along the galactic plane and less than 2° perpendicular to it. Our measurements indicate that the flux density from this region in a 40-μ band width centered at a wavelength of 100 μ is $1.8 \pm 0.8 \times 10^{-19}$ W m^{-2} Hz^{-1}. The source brightness averaged over our 2°.3 beam width is 1.5×10^{-3} erg sec^{-1} cm^{-2} μ^{-1} sterad^{-1}, giving a brightness temperature at 100 μ of 16° K. We believe this to be the first object outside the solar system that has been detected in the region of the spectrum from 25 μ to 1000 μ (1 mm).

The galactic nucleus is obscured from observation in the visible spectrum by interstellar extinction. Observations of the galactic center have been made in the radio region from 2 to 75 cm and in the middle infrared out to 3.4 μ. The spectrum of the radio sources suggests that they are synchrotron radiation from relativistic electrons in a magnetic field and thermal radiation from a hot ionized gas (Burke 1965). The observations at 1.6–3.4 μ have been interpreted as the faint long-wavelength tail of 4000° K black-body emission, which is believed to characterize the stars that populate the galactic nucleus (Becklin and Neugebauer 1968). Our measurement at 100 μ gives a flux density which is 3 orders of magnitude larger than that observed in the radio and middle-infrared regions and 5 orders of magnitude greater than a Rayleigh-Jeans extrapolation of 4000° K black-body emission. It appears that our measurement cannot be explained by the mechanisms believed responsible for those emissions. The spectrum of the observed emission of the galactic center is illustrated in Figure 1.

II. INSTRUMENTATION

The observations at 100 μ were made with a germanium bolometer at the focus of a 1-inch-aperture f/1.2 crystal quartz lens. The bolometer, lens, and associated 100-μ filter system were cooled to 1.8° K by liquid helium at the ambient atmospheric pressure of 13 Torr encountered at 27-km altitude. The filter system included (1) the 2.3-mm-thick crystal quartz lens, (2) 0.1-mm-thick black polyethylene, and (3) No. 300 electroformed metal mesh, each at the temperature of liquid helium; (4) powdered barium fluoride in white polyethylene, (5) black polyethylene, and (6) No. 300 mesh, each on the cold radiation shield; and (7) a 1-mm-thick warm crystal quartz window. The filter had an effective wavelength of 100 μ and an effective band width of 40 μ; and the peak transmission was 12 per cent. The full beam width at half-power was 2°3. The beam was reflected from a 45° gold-plated aluminum mirror outside the Dewar; the mirror was rotated at 8.3 Hz about an axis 0°6 from its normal, which caused the telescope beam to wobble in an ellipse of horizontal axis 2°3 and elevation axis 1°6. The bolometer preamplifier was followed by two phase-sensitive detectors operating in phases separated

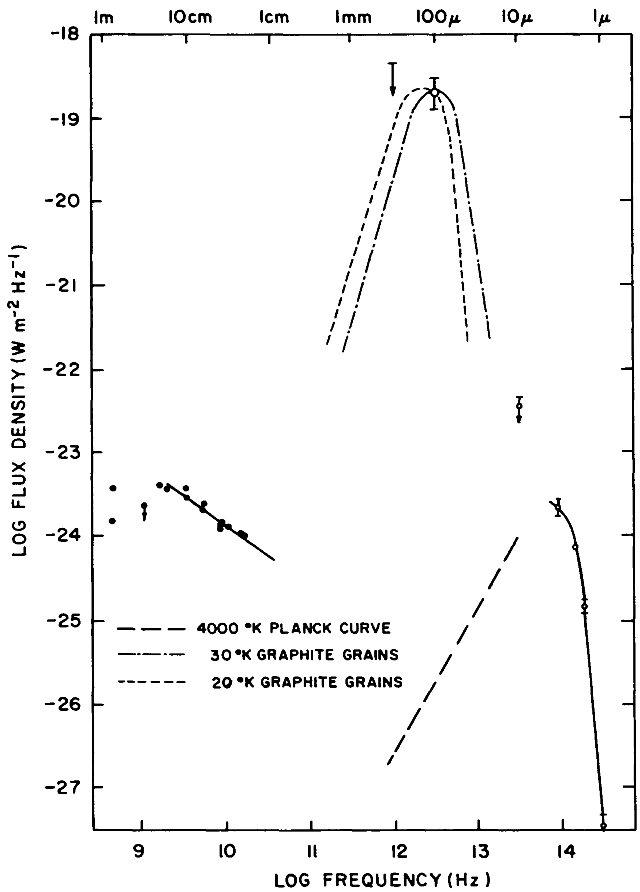

FIG. 1.—Infrared and radio spectrum of the galactic center. The 100-μ flux density and the 320-μ upper limit (Hoffmann *et al.* 1967) are for a region 2° × 6°5. The radio and middle-infrared points, taken from Becklin and Neugebauer (1968), are shown for reference. They are for a small source 3′5 in diameter and hence cannot be directly compared with the 100-μ emission. The 20° and 30° K curves for graphite grains are normalized to the 100-μ observation. The 4000° K curve is normalized to the 3.4-μ observation.

by 90°. This provided a system which was sensitive to discrete sources or flux gradients in the sky but not to constant and uniform instrumental, sky, or cosmic background. The direction of the gradient detected by output channel 1 turned out to be very nearly along the galactic plane during observations, while the gradient detected by channel 2 was perpendicular to the plane of the Galaxy.

The instrument was lofted to an elevation of 27 km with a gondola similar to that used in previous flights (Hoffmann *et al.* 1967). The phase-sensitive detector outputs were recorded on board by a 35-mm camera photographing meter pointers on continuously moving film. The film also recorded clock, pressure, and magnetometer readings. A significant change from previous flights was the addition of a crude azimuth-stabilization system operated by ground control. The telescope operated at a fixed elevation angle and at an azimuth established relative to a flux-gate magnetometer which could be commanded to orient the package to any azimuth angle. The electronic circuitry in the package superposed on the azimuth stabilization a sweep with a width of 20° and a period of 3 minutes. The combination of this azimuth sweep and the sidereal motion produced a raster scan of a limited region of the sky approximately in the shape of a spherical parallelogram (Fig. 2). For this flight the elevation angle was set at 27° in order to provide observations of the galactic center nearly due south.

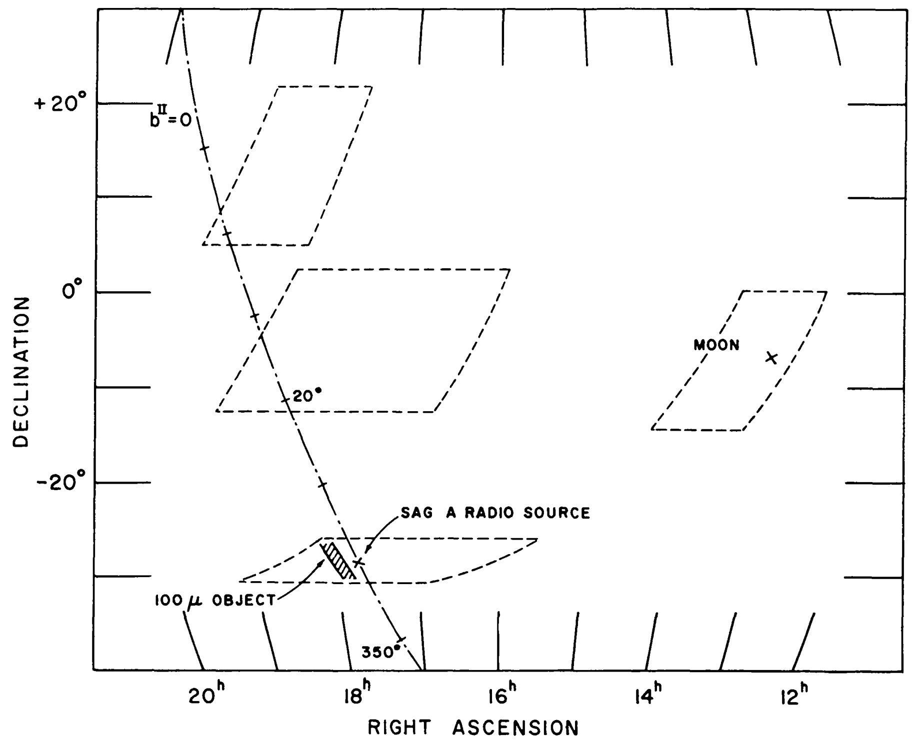

FIG. 2.—Portions of the sky scanned during the balloon flight of July 30, 1968. The Moon and the 100-μ extended source in the direction of the galactic center are indicated. Displacement of the 100-μ source relative to the radio source Sagittarius A is within the present uncertainty of the position determination.

III. OBSERVATIONS

During the flight of July 30 four regions of the sky were scanned as shown in Figure 2. Only the Moon and the object in the direction of the galactic center were detected. Objects with less than one-fourth the brightness of the galactic center would not have been detected. Approximately 40 scans of the galactic center were obtained during a period of an hour. The signal was clearly identifiable as an astronomical source by its sidereal motion and persistence over many scans.

There was no observable signal in channel 1, indicating that the flux gradient along the galactic plane was small. The shape of the signal from channel 2 agrees with laboratory measurements for a line source. This implies that the extent of the source perpendicular to the galactic plane is less than a beam diameter (2°.3). The signal appears to be constant to within 25 per cent along the region of the galactic plane scanned. There is no evidence for a greater intensity at the center of the emitting region. The drift in right ascension of the beam crossing the source relative to its declination agrees well with the orientation of the galactic plane (Fig. 2). The extent of the source along the galactic plane appears to be at least 6°.5. This is a lower limit, because the source runs beyond each extreme of the raster scan. Later scans of a region covering 20° in galactic longitude showed no signal.

IV. POSITION OF SOURCE

The direction of observation was determined from the magnetometer readings, the initial setting of the telescope, and the command sequence. An independent check of the validity of the procedure and the initial setting was obtained from observations of the Moon early in the flight. These observations agree to within $\pm 1°$ with the ephemeris lunar position. The resulting position for the 100-μ source shown in Figure 2 lies about 3° from the galactic plane. This apparent displacement could be caused by an uncertainty in the command sequence. For this reason we believe that our observations are consistent with the assumption that the 100-μ source is in the direction of the galactic center.

V. INTENSITY OF SOURCE

The instrumental sensitivity was determined by laboratory calibration with a thermal source and by observations of the Moon early in the flight. Some uncertainty attends both of these calibrations because of uncertainty of the atmospheric transmission in the laboratory calibration and because of a lack of assurance that any of the scans crossed the center of the lunar disk. However, they agree to within 20 per cent of each other and to within a factor of 3 of the sensitivity calculated from the bolometer, filter, chopper, and electronics characteristics. The mean atmospheric absorption above 27 km between 80 and 120 μ is less than 5 per cent and can be neglected (Turon-Lacarrieu and Verdet 1968). On this basis we estimate that the flux density at 100 μ integrated over the 6°.5 extent of the source observed is $1.8 \pm 0.8 \times 10^{-19}$ W m^{-2} Hz^{-1}.

VI. INTERPRETATION

While we have no unique proof that the source is, in fact, the galactic center, its direction, shape, orientation, and unusual intensity argue in favor of this identification. On the assumption that the source is at the distance of the galactic center (10 kpc), the total emission in our 40-μ band width centered at 100 μ and integrated over 6°.5 along the galactic plane is 2.7×10^{42} ergs sec^{-1}, or $7 \times 10^8 L_\odot$. This is approximately 3 per cent of the total luminosity believed to be associated with our Galaxy.

The total mass in the region of the galactic nucleus corresponding to the observed source (a cylinder 1100 pc in diameter by 350 pc thick) is given by Schmidt (1965) as $8 \times 10^9 M_\odot$, approximately 10 per cent of the total mass in the Galaxy. This implies a mass-to-luminosity ratio of 12 $M_\odot/L_\odot$ for the 100-μ luminosity alone, suggesting that a substantial fraction of the radiation of the galactic nucleus, and perhaps of the Galaxy as a whole, is emitted in the far-infrared region of the spectrum. This appears to be the case in some Seyfert galaxies (Low and Kleinmann 1968), but there has been no previous evidence that the dominant emission from an apparently normal spiral galaxy is in the far-infrared.

VII. INTERSTELLAR-GRAIN EMISSION?

A possible mechanism for the observed far-infrared emission is thermal emission from interstellar grains heated by the absorption of starlight. If we assume this explanation, we can draw some approximate conclusions about the nature and environment of the grains.

Stein (1966) has given a model for interstellar-grain emission with which he estimates the intensity of far-infrared radiation in the galactic plane. His model assumes that the grain size and density and the total radiation-energy flux in the solar neighborhood represent a reasonable approximation to the mean values over the galactic plane. Our observed intensity is 30 times Stein's estimate. Hence, if our observation is to be explained by this model, the mean grain density and the radiation-energy flux must be considerably higher in the region of the grains than in the solar neighborhood.

For thermal emission the physical temperature of the grains must be greater than the brightness temperature (16° K). Figure 1 shows emission curves for grains with an absorption efficiency proportional to λ^{-2} (graphite) at temperatures of 20° and 30° K. Our observations are not sufficient to specify more than a lower limit to the grain temperature. However, this lower limit appears to rule out the very low temperatures around 4° K required for solid hydrogen mantles in the grains (Hoyle and Wickramasinghe 1967).

Further observations are required to determine whether the far-infrared emission can be explained by grain emission models. There remains the possibility that the present observations reveal some new, unknown phenomena associated with the galactic nucleus.

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REFERENCES

Becklin, E. E., and Neugebauer, G. 1968, *Ap. J.*, **151**, 145.
Burke, B. F. 1965, *Ann. Rev. Astr. and Ap.*, **3**, 275.
Hoffmann, W. F., Woolf, N. J., Frederick, C. L., and Low, F. J. 1967, *Science*, **157**, 187.
Hoyle, F., and Wickramasinghe, N. C. 1967, *Nature*, **214**, 969.
Low, F. J., and Kleinmann, D. E. 1968, *A.J.*, **73**, 868.
Schmidt, M. 1965, in *Galactic Structure*, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), p. 513.
Stein, W. A. 1966, *Ap. J.*, **144**, 318.
Turon-Lacarrieu, P., and Verdet, J. P. 1968, *Ann. d'ap.*, **31**, 237.